

CLAIMS

What is claimed is:

1. A method for determining an axial force acting on each one of a plurality of roller cones on a roller cone drill bit during drilling, comprising:  
2. calculating, from a geometry of cutting elements on each of the roller cones and an earth formation being drilled by the drill bit, an axial force acting on each of the cutting elements;  
3. incrementally rotating the bit and recalculating the axial forces acting on each of the cutting elements;  
4. repeating the incrementally rotating and recalculating for a selected number of incremental rotations; and  
5. combining the axial force acting on the cutting elements on each one of the roller cones.

1. 2. The method as defined in claim 1 wherein the axial force acting on each of the cutting elements totals an axial force applied to the drill bit.

1. 3. The method as defined in claim 2 wherein an incremental axial movement of the drill bit corresponding to the incrementally rotating is adjusted to cause the axial force on each of the cutting elements to total the axial force applied to the drill bit, the axial force acting on each of the cutting elements determined with respect to a predetermined relationship between depth of penetration and axial force applied for the cutting element geometry and the earth formation.

1 4. The method as defined in claim 3 wherein the predetermined relationship is  
2 determined by ~~laboratory experiment~~ comprising impressing a cutting element having  
3 known geometry onto a selected earth formation, while ~~measuring force on the cutting~~  
4 element and a corresponding depth of penetration of the cutting element into the selected  
5 earth formation.

1 5. A method for determining a volume of formation cut by each one of a plurality of  
2 roller cones on a drill bit drilling in earth formations, comprising:  
3       selecting bit design parameters, comprising at least a geometry of a cutting  
4       element on the drill bit;  
5       selecting an earth formation;  
6       calculating from the selected bit design parameters and the selected earth  
7       formation, parameters for a crater formed when each one of a plurality of cutting  
8       elements on each of the roller cones contacts the earth formation, the parameters  
9       including at least a volume of the crater;  
10      incrementally rotating the bit, and repeating the calculating of the crater  
11      parameters for a selected number of incremental rotations; and  
12      combining the volume of each crater formed by each of the cutting elements on each of  
13      the roller cones to determine the volume of formation cut by each of the roller cones.

1 6. The method as defined in claim 5 wherein the volume of each of the craters is  
2 determined by:  
3 determining an axial force on each of the cutting elements;  
4 calculating, from the axial force on each of the cutting elements, an expected  
5 depth of penetration and projected area of contact between each of the cutting elements  
6 and the earth formation; and  
7 calculating the volume of each of the craters from the expected depth of  
8 penetration and projected area of contact.

1 7. The method as defined in claim 6 further wherein the axial force acting on each of  
2 the cutting elements totals an axial force applied to the drill bit.

1 8. The method as defined in claim 7 wherein an incremental axial movement of the  
2 drill bit corresponding to the incrementally rotating is adjusted to cause the axial force on  
3 each of the cutting elements to total the axial force applied to the drill bit, the axial force  
4 acting on each of the cutting elements determined with respect to a predetermined  
5 relationship between depth of penetration and axial force applied for the cutting element  
6 geometry and the earth formation.

1 9. The method as defined in claim 8 wherein the predetermined relationship is  
2 determined by laboratory experiment comprising impressing a cutting element having  
3 known geometry onto a selected earth formation, while measuring force on the cutting  
4 element and a corresponding depth of penetration of the cutting element into the selected  
5 earth formation.

1 10. A method for balancing axial forces acting on each one of a plurality of roller  
2 cones on a roller cone drill bit during drilling, comprising:  
3 calculating, from a geometry of cutting elements on each of the roller cones and  
4 an earth formation being drilled by the drill bit, an axial force acting on each of the  
5 cutting elements;  
6 incrementally rotating the bit and recalculating the axial forces acting on each of  
7 the cutting elements;  
8 repeating the incrementally rotating and recalculating for a selected number of  
9 incremental rotations;  
10 combining the axial force acting on the cutting elements on each one of the roller  
11 cones; and  
12 adjusting at least one bit design parameter, and repeating the calculating the axial force,  
13 incrementally rotating and combining the axial force, until a difference between the  
14 combined axial force on each one of the roller cones is less than a difference between the  
15 combined axial force determined prior to adjusting the at least one initial design  
16 parameter.

1 11. The method as defined in claim 10 wherein the axial force acting on each of the  
2 cutting elements totals an axial force applied to the drill bit.

1 12. The method as defined in claim 11 wherein an incremental axial movement of the  
2 drill bit corresponding to the incrementally rotating is adjusted to cause the axial force on  
3 each of the cutting elements to total the axial force applied to the drill bit, the axial force  
4 acting on each of the cutting elements determined with respect to a predetermined  
5 relationship between depth of penetration and axial force applied for the cutting element  
6 geometry and the earth formation.

1 13. The method as defined in claim 12 wherein the predetermined relationship is  
2 determined by laboratory experiment comprising impressing a cutting element having  
3 known geometry onto a selected earth formation, while measuring force on the cutting  
4 element and a corresponding depth of penetration of the cutting element into the selected  
5 earth formation.

1 14. The method as defined in claim 10 wherein the at least one bit design parameter  
2 comprises a number of cutting elements on at least one of the cones.

1 15. The method as defined in claim 10 wherein the at least one bit design parameter  
2 comprises a location of cutting elements on at least one of the cones.

16. A method for balancing a volume of formation cut by each one of a plurality of  
2 roller cones on a drill bit drilling in earth formations, comprising:  
3       selecting bit design parameters, comprising at least a geometry of a cutting  
4 element on the drill bit;  
5       selecting an earth formation;  
6       calculating from the selected bit design parameters and the selected earth  
7 formation, parameters for a crater formed when each one of a plurality of cutting  
8 elements on each of the roller cones contacts the earth formation, the parameters  
9 including at least a volume of the crater;  
10      incrementally rotating the bit, and repeating the calculating of the crater  
11 parameters for a selected number of incremental rotations;  
12      combining the volume of each crater formed by each of the cutting elements on  
13 each of the roller cones to determine the volume of formation cut by each of the roller  
14 cones; and  
15      adjusting at least one of the bit design parameters, and repeating the calculating the crater  
16 volume, incrementally rotating and combining the volume until a difference between the  
17 combined volume cut by each of the cones is less than the combined volume determined  
18 prior to the adjusting the at least one of the bit design parameters.

17. The method as defined in claim 16 wherein the volume of each of the craters is  
2 determined by:  
3       determining an axial force on each of the cutting elements;  
4       calculating, from the axial force on each of the cutting elements, an expected  
5 depth of penetration and projected area of contact between each of the cutting elements  
6 and the earth formation; and  
7       calculating the volume of each of the craters from the expected depth of  
8 penetration and projected area of contact.

1 18. The method as defined in claim 17 wherein the axial force acting on each of the  
2 cutting elements totals an axial force applied to the drill bit.

1 19. The method as defined in claim 18 wherein an incremental axial movement of the  
2 drill bit corresponding to the incrementally rotating is adjusted to cause the axial force on  
3 each of the cutting elements to total the axial force applied to the drill bit, the axial force  
4 acting on each of the cutting elements determined with respect to a predetermined  
5 relationship between depth of penetration and axial force applied for the cutting element  
6 geometry and the earth formation.

1 20. The method as defined in claim 16 wherein the at least one bit design parameter  
2 comprises a number of cutting elements on at least one of the cones.

1 21. The method as defined in claim 16 wherein the at least one bit design parameter  
2 comprises a location of cutting elements on at least one of the cones.

1 22. A method for optimizing a design of a roller cone drill bit, comprising:  
2 simulating the bit drilling through a selected earth formation;  
3 adjusting at least one design parameter of the bit;  
4 repeating the simulating the bit drilling; and  
5 repeating the adjusting and simulating until an optimized design is determined.

1 23. The method as defined in claim 22 wherein the at least one design parameter  
2 comprises a parameter selected from the group of a number of cutting elements on each  
3 one of a plurality of roller cones, cutting element type, and a number of rows of cutting  
4 elements on each one of the plurality of roller cones.

27 24

- 1 28. The method as defined in claim 27, wherein the calculated crater parameters are
- 2 derived from laboratory tests comprising a cutting element having selected geometry
- 3 being impressed on an earth formation sample with a selected force, the tests generating
- 4 at least a correspondence between penetration depth of said cutting element into the
- 5 formation and the selected force.

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1 24. The method as defined in claim 22 wherein the optimized design is determined  
2 when a rate of penetration of the bit through the selected earth formation is maximized.

1 25. The method as defined in claim 22 wherein the optimized design is determined  
2 when axial force on the bit is substantially balanced between the roller cones.

1 26. The method as defined in claim 22 wherein the optimized design is determined  
2 when a volume of formation cut by the bit is substantially balanced between the roller  
3 cones.

1 27. The method as defined in claim 22 wherein the simulating comprises:  
2 selecting bit design parameters;  
3 selecting drilling parameters;  
4 selecting an earth formation to be represented as drilled;  
5 calculating from the selected parameters and the formation, parameters for a  
6 crater formed when one of a plurality of cutting elements on the bit contacts the earth  
7 formation, the cutting elements having known geometry;  
8 calculating a bottomhole geometry, wherein the crater is removed from a  
9 bottomhole surface;  
10 incrementally rotating the bit;  
11 repeating the calculating of the crater parameters and the bottomhole geometry based on  
12 calculated roller cone rotation speed and geometrical location with respect to rotation of  
13 the bit about its axis.